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Optical Measurement of Propeller Blade Deflections in a Spin Facility

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Summary

A nonintrusive optical system for measuring propeller blade deflections has been used in the NASA Lewis dynamic spin facility. Deflection of points at the leading and trailing edges of a blade section can be obtained with a narrow light beam from a low-power helium-neon laser. This report describes a system used to measure these deflections at three spanwise blade locations. Modifications required to operate the lasers in a near-vacuum environment are also discussed.

Introduction

The propfan consists of thin, flexible blades with high compound sweep, as shown in figure 1. Because of this unusual blade geometry the blade deflections (due to centrifugal and aerodynamic loading) are nonlinear. Currently, finite element analysis is used to predict the steady-state displacements of these rotating blades. Because of the nonlinear nature of the displacements it was desired to verify the finite element code experimentally. This verification will be accomplished by spinning the propfan blades in the NASA Lewis dynamic spin facility (DSF) (refs. 1 to 3) and measuring the blade deflections. The DSF is shown in figure 2. These experimental blade displacements will then be compared with the blade displacements predicted by the finite element analysis. In order to reduce the complexity of the experimental verification, the airloads were removed from the problem by spinning the blades in a near vacuum. This near vacuum prevented the aerodynamic forces from significantly influencing the blade displacements and will allow the experimental displacements to be correlated with those predicted by finite element analysis without the added complexity associated with aerodynamic blade loading.

Because of the unusual geometric shape and nonlinear deflection of the rotating propfan blades, a special nonintrusive blade measurement system was needed. One such measurement system using optics was developed at the NASA Lewis Research Center and is described in references 4 and 5. This nonintrusive optical measurement system had been used previously in wind tunnels and test cells. Deflection of points at the leading and trailing edges of a blade section (chord) can be obtained with a narrow light beam from a low-power

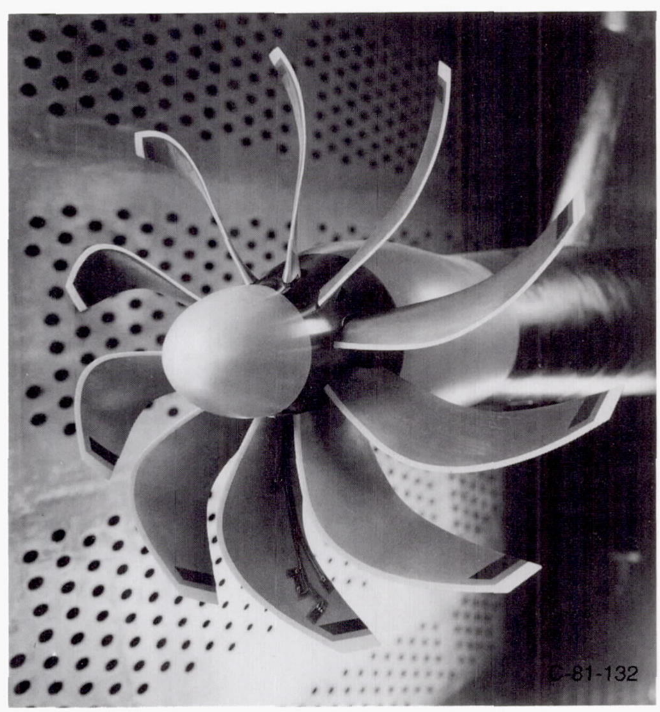


Figure 1.—Propfan.

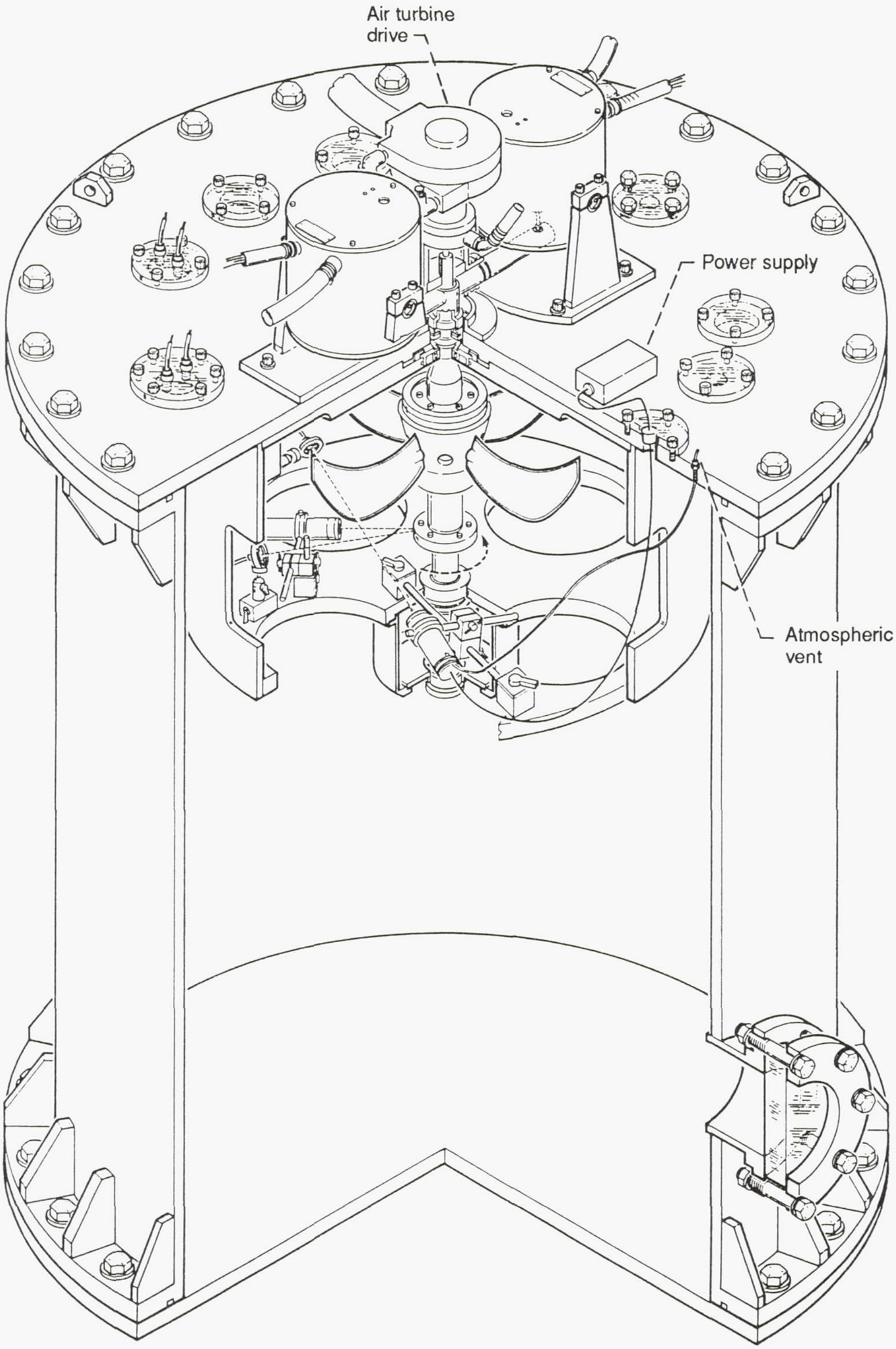


Figure 2.—Dynamic spin facility.

helium-neon laser. This report describes this optical blade measurement system. Modifications required to operate the lasers in a near-vacuum environment are also discussed.

Optical Measurement System

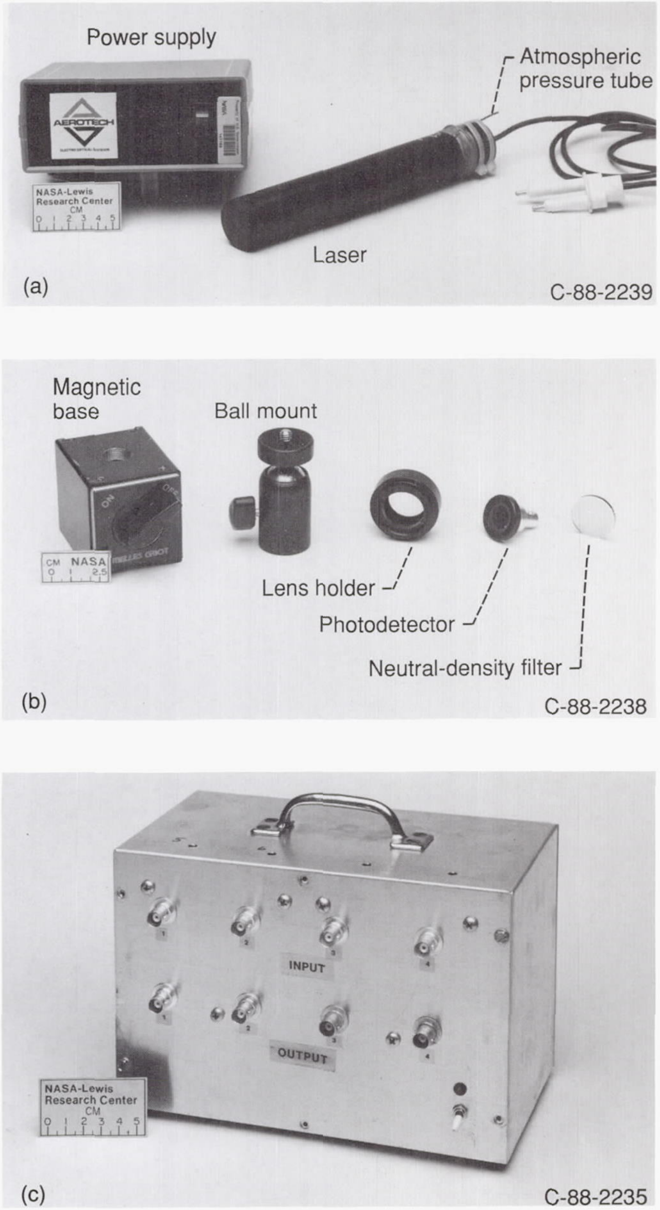
The optical blade deflection measurement system comprises 0.5-mW helium-neon lasers, Schottky barrier photodetectors (photodiodes), neutral-density filters, signal amplifiers, an output-signal-recording device, and a digitizer. These components, except for the recording device and digitizer, are shown in figure 3. The optical blade measurement system installed in the DSF is shown in figure 4. Figure 5 is a schematic of the installed optical measurement system including the peripheral components.

Propfans typically consist of eight or more blades. For ease in properly aligning the laser beams a subset number of blades are usually tested. Four blades per propfan have been used in testing to date.

The unobstructed laser beams are oriented so that they pass through the propfan blades' plane of rotation and impinge on the photodetector (figs. 4 and 5), producing positive voltage signals. The neutral-density filters are used to attenuate the laser light level density to that recommended by the photodetector manufacturer and to facilitate adjusting signal levels. The neutral-density filters are put in front of the detector, and both are held in place with a lens holder, as shown in figures 3 and 8.

As the blades rotate, interrupting the laser beams, the photodetectors produce negative voltage pulses. A narrow light beam, such as that from a laser, is crucial to the production of proper square-wave voltage pulses, and square-wave voltage pulses are required for proper blade deflection analysis. Shown in figures 6(a) and (b) are voltage pulses produced by lasers mounted at radii near the tip and 3/4 span, respectively, of the SR3 propfan blades. Three lasers have been used for deflection measurement to date. In addition, another laser is positioned so that its beam reflects from a mirror mounted on the rotor shaft to a photodetector (figs. 4 and 5). As the rotor shaft turns, the mirror passes in front of the laser beam, reflecting the beam to a photodetector and providing a once-per-revolution positive voltage pulse. Shown in figure 7 is the voltage pulse produced by the once-per-revolution laser.

The photodetector signals are conducted to close-coupled amplifiers that drive coaxial 50-Ω transmission lines (up to 100 ft in length) to the control room, where the signals are then recorded on a wideband II frequency-modulated (FM) tape recorder. The taped signals are digitized and input into the blade measurement computer code (refs. 4 and 5) for analysis. Displacements are calculated relative to the once-per-revolution signal. The code is used to calculate the twist and bending of the three blade sections corresponding to the three spanwise measurement stations.



(a) Laser source.
(b) Optical hardware.
(c) Photodetector amplifier.

Figure 3.—Components of optical measurement system.

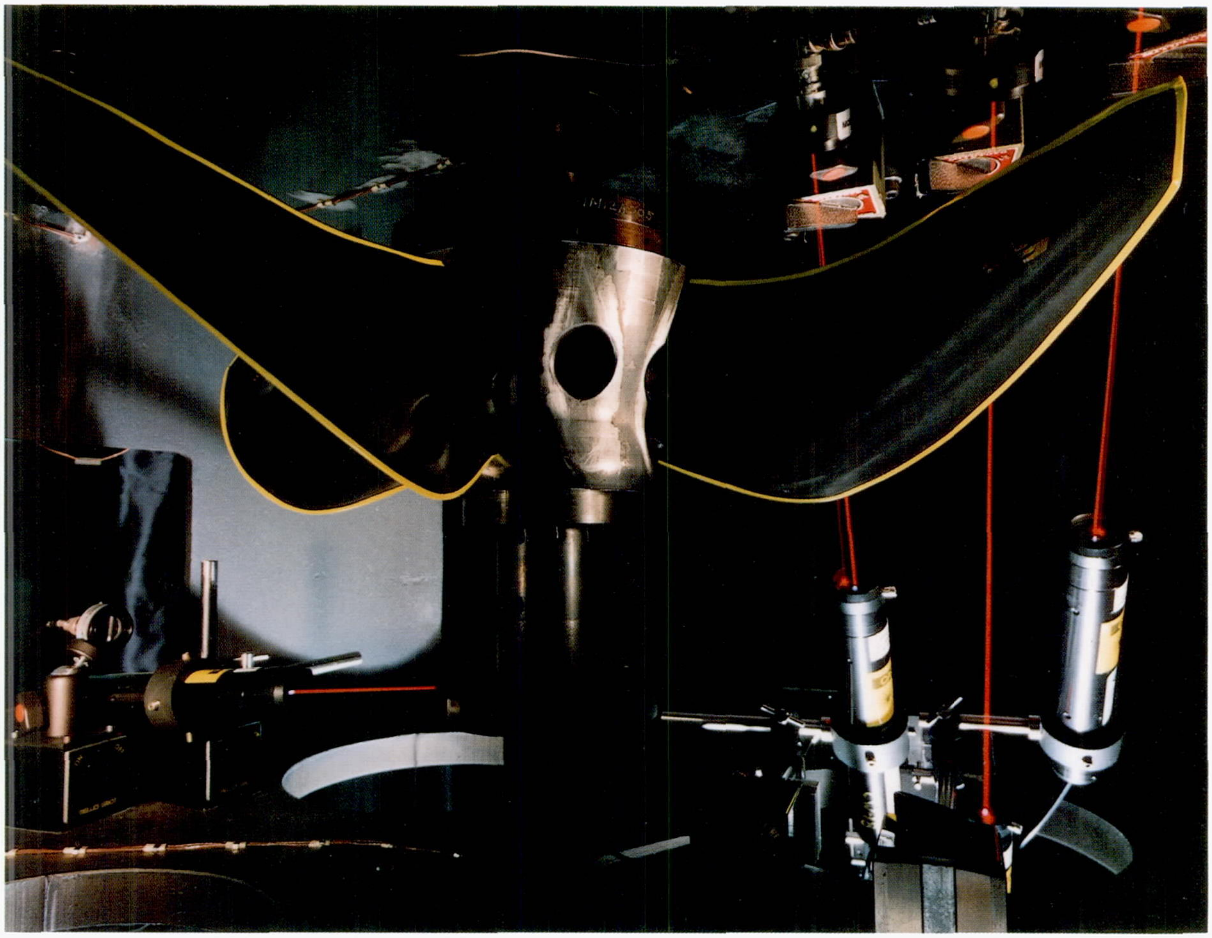


Figure 4.—Optical measurement system installed in dynamic spin facility.

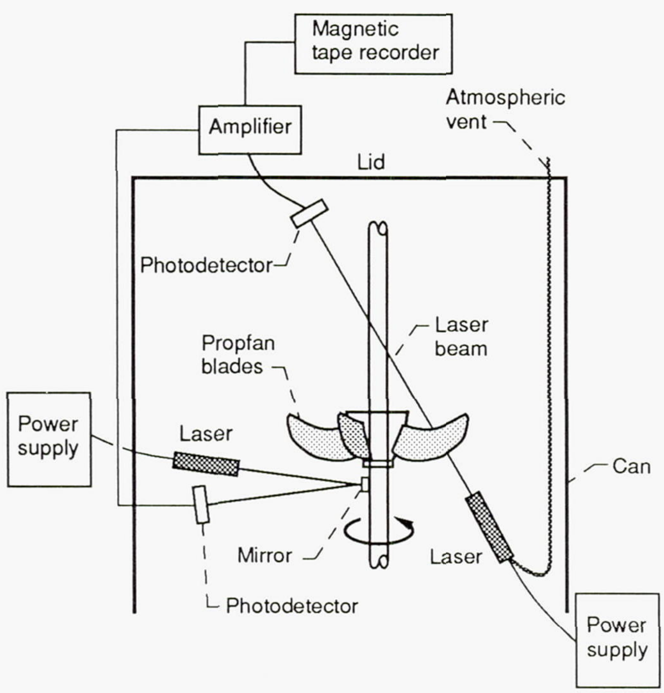
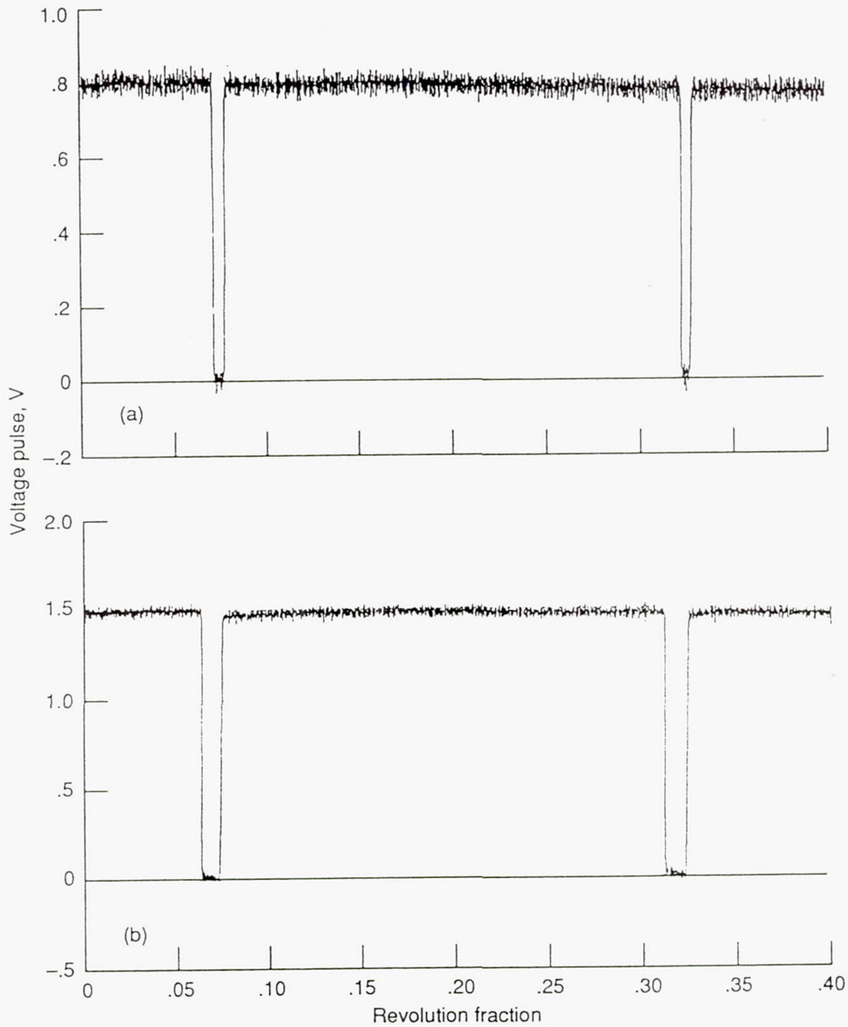


Figure 5.—Schematic of optical measurement system.



(a) Near blade tips.
(b) At 3/4-span location.

Figure 6.—Voltage pulses produced as result of four propfan blades rotating at 8000 rpm interrupting laser beam–photodetector combination.

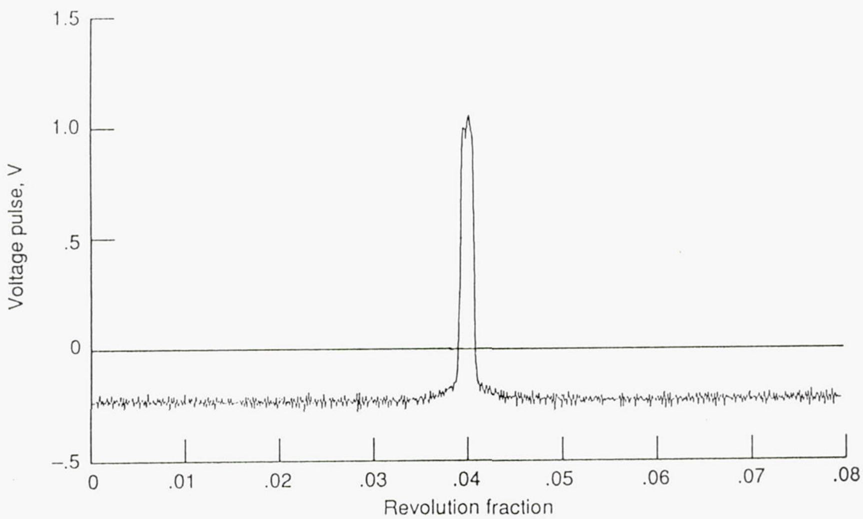


Figure 7.—Voltage pulse produced as a result of rotor-shaft-mounted mirror rotating at 8000 rpm and reflecting laser beam to photodetector once per revolution.

Adaptation of Optical Measurement System to Dynamic Spin Facility

Incorporating the optical measurement system into the DSF posed some new problems. Previous use of this system had been in wind tunnels and test cells, where the blades rotated in a vertical plane, atmospheric air pressures were not extremely low, and there was generally plenty of space to mount lasers and photodetectors. The lasers were often at great distances from the blades. In the DSF, however, the blades rotate in a horizontal plane in a vacuum of about 1 torr. In addition, the DSF provides a limited space to mount lasers and photodetectors. The optical measurement system requires that the blades rotate between the laser beam source and the detector. Since there is more space below the blades than above and since the detectors are smaller than the lasers, it was decided to mount the detectors above the blades on the lid, and the lasers below the blades on the bottom of the can, as shown in figures 4 and 5.

As stated previously, the laser system had never been operated in near-vacuum conditions. In the DSF, however, the lasers had to operate at a pressure of about 1 torr. This presented a problem in that the lasers had exposed electrodes at elevated potentials. When the lasers were operated at this low atmospheric pressure, the air surrounding the electrodes ionized, shorting the laser electrodes and extinguishing the lasers. Team effort produced a workable solution to this critical problem. The solution consisted of sealing the glass plasma tube away from the low-pressure environment within its aluminum casing in such a way that the laser beam exit was unobstructed. The space between the glass plasma tube and its external casing, where the electrodes are located, was referenced to atmospheric pressure by means of small-bore plastic tubing that ran from the laser casing through the DSF lid. This solution was effective in preventing the air surrounding the electrodes from ionizing.

Photodetector Mounting Apparatus

The method of mounting the detectors had to be versatile enough to accommodate the various geometries of the different propfan blades as well as the different blade setting angles. The method of mounting the detectors had to ensure that they did not fall into the rotating blades. Because of these requirements it was decided to use magnetic bases in conjunction with lens holders and ball mounts to mount the detectors, as shown in figures 3 and 8. By simply turning a lever on the magnetic base, as shown in figure 8, the magnet could be turned off, allowing easy positioning of the base. When the base was in its proper position, the lever could be turned again, turning on the magnet and securing the base and the diode to the DSF lid. The ball mount allowed the photodetector to be oriented at various angles with respect to the DSF lid. The magnetic bases and the ball mounts provided the freedom necessary for properly aligning the detector with the laser beam.

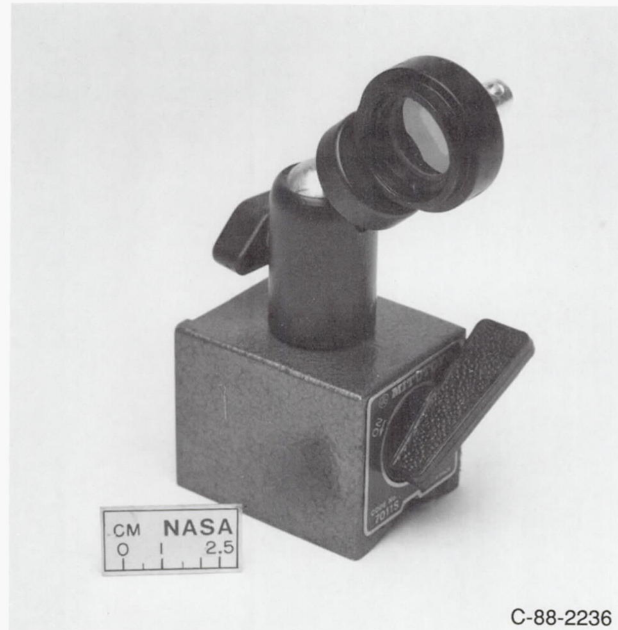


Figure 8.—Photodetector mounting apparatus showing photodetector ball mount and magnetic base.

Laser Mounting Apparatus

The means by which the lasers were mounted had to accommodate the different blade configurations and blade setting angles. The laser mounting apparatus also had to allow for the horizontal, vertical, and rotational adjustments necessary for properly aligning the lasers. The laser mounting apparatus consisted of magnetic bases, posts, base clamps, and

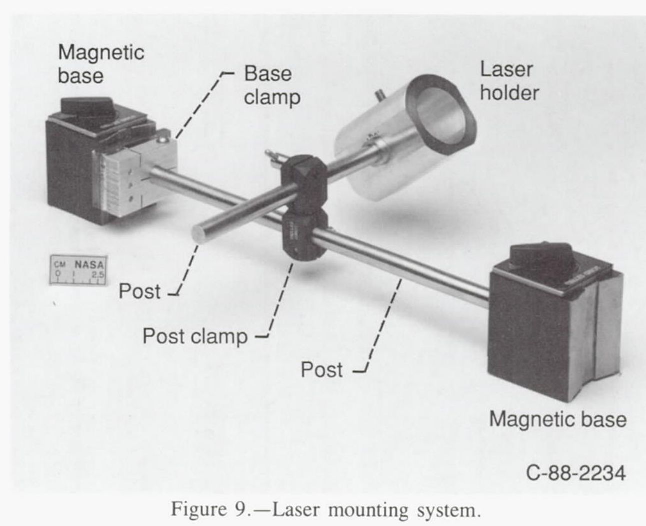


Figure 9.—Laser mounting system.

post clamps. A horizontal post was threaded into one magnetic base and secured to another magnetic base on its opposing end by a base clamp. The laser mounting post was joined at a right angle to the horizontal post by a post clamp. This provided two translational and two rotational degrees of freedom necessary for properly aligning the lasers with respect to a specific blade station. This arrangement is shown in figure 9.

Photodetector Amplifiers

The photodetector amplifiers are needed to drive the voltage signals from the detectors through a coaxial cable to a recording device. Previous use of the laser system in wind tunnel tests incorporated amplifiers powered by batteries. One individual amplifier was required for each detector. This configuration has several drawbacks. The first drawback is that when many detectors are present, many amplifiers are needed, taking up much space and creating a maze of coaxial cables. The second drawback is that the internal batteries eventually run down causing a loss of voltage pulse signal—an undesirable result, especially if it occurs during a test.

Because of the drawbacks of this amplifier configuration, a new configuration was designed. The new configuration, shown in figure 3(c), combines four amplifiers into one unit and does not require internal batteries to operate. This new design conserves space and eliminates the possibility of the amplifier running down (owing to low battery voltage) during a test.

Figure 10 is a circuit schematic of one photodetector amplifier. This circuit is capable of driving output voltage levels of ± 1 V through a terminated 50- or 75-Ω coaxial cable 100 ft in length. This circuit also provides rise times on the order of 1 μs. Four of these amplifiers were paralleled from 15-, -15-, and -12-V power supplies. Commercial solid-state power supplies were utilized but are not shown schematically in figure 10. It is important to note that the photodetectors must be floating from any ground, since the 12-V bias supply would be shorted if the detector became grounded. The 200-Ω potentiometer allows adjustment of the output signal zero.

Laser Setup Procedure

The propfan blades are mounted in the DSF so that the pressure surfaces are facing the top of the DSF (figs. 4 and 11) and thus are spun clockwise (looking vertically up toward the lid) during testing. It is best to install the lasers so that the pressure (concave) surface of the blade intersects the laser beams before the suction (convex) surface of the blade does, as shown in figure 11. This helps prevent reflection of the laser beams from the convex suction surface. For generation of a proper voltage pulse the laser beam should be shadowed from the photodetectors as soon as the blade leading or trailing edge intersects the laser beams, and the laser beams should impinge on the photodetectors as soon as the blade trailing or leading edge exits the laser beam paths.

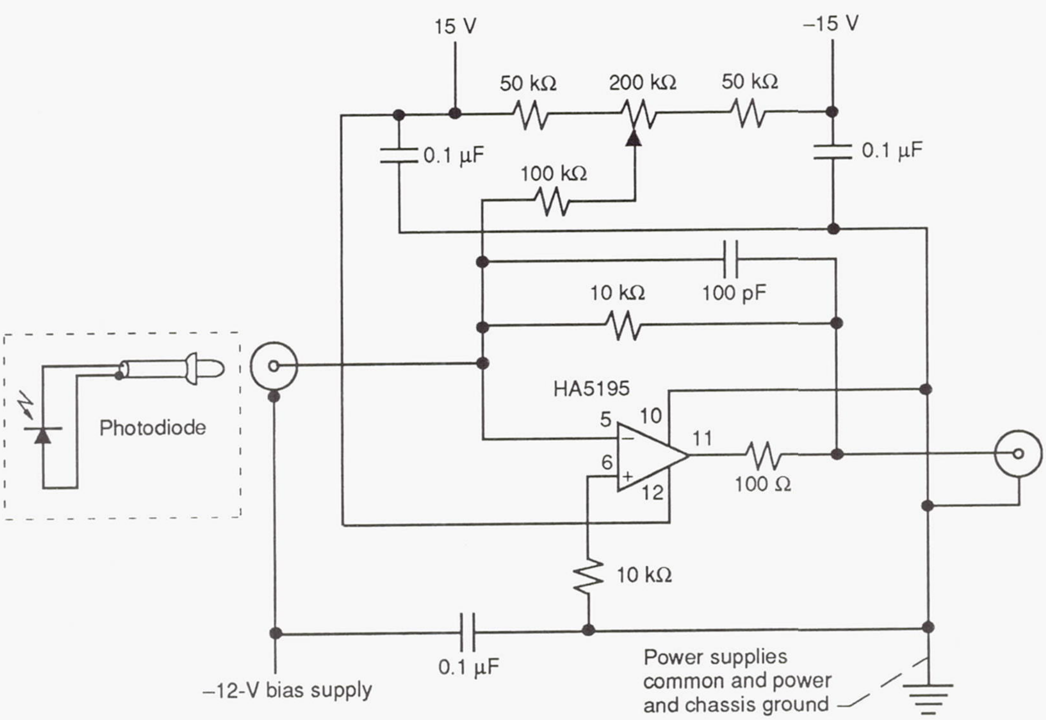


Figure 10.—Schematic of photodetector amplifier.

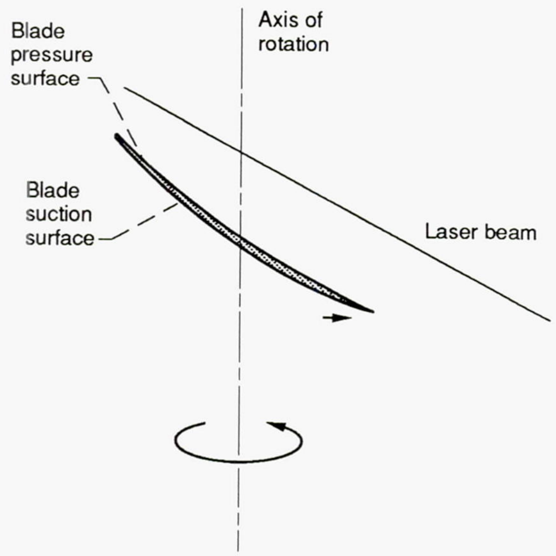


Figure 11.—Orientation of blade surfaces with respect to laser beam.

The computer code used to calculate the deflections from the voltage pulse data required that the lasers be aligned with respect to the propfan blades in a particular manner. For ease in aligning the lasers, templates are made to fit a specific blade. These templates extend from the blade tip to the spanwise locations desired for measurement. These templates allow the blade chord on the pressure surface to be marked with a felt-tip pen from the leading edge to the trailing edge so that the marked chord lines lie in a plane parallel to the axis of rotation of the propfan blades and in a plane perpendicular to their pitching axis, as shown in figure 12. The midchord points are also marked for use in the final laser alignment.

Once the blade chords are marked and the templates are removed, two rubber wedges are inserted between the bottom of the propfan blade and the hub. These wedges force the blade outward from the hub, seating the blade shank in the hub. This simulates the effect of centrifugal force that the blade will experience during testing and positions the marked blade chords in the proper radial orientation with respect to the axis of rotation.

The lasers are then positioned so that the laser beams are aligned with and intersect the leading and trailing edges of the marked blade chords. This serves to position the laser beams at the blade chord setting angles (fig. 12). Once the three laser beams are oriented at the three blade chord setting angles at the three respective spanwise blade stations, a digital protractor is used to record the setting angle (angle of each laser with respect to the horizontal) of each laser beam. Once the angles are recorded, each laser is rotated so that the laser beam rotates in the plane of the chord line (perpendicular to the pitch axis) and the angle between the lasers and the horizontal is decreased by 8° to 10°, as shown in figure 13. The lasers are then translated horizontally away from the propfan blade in the plane of the blade chord lines so that each laser beam intersects

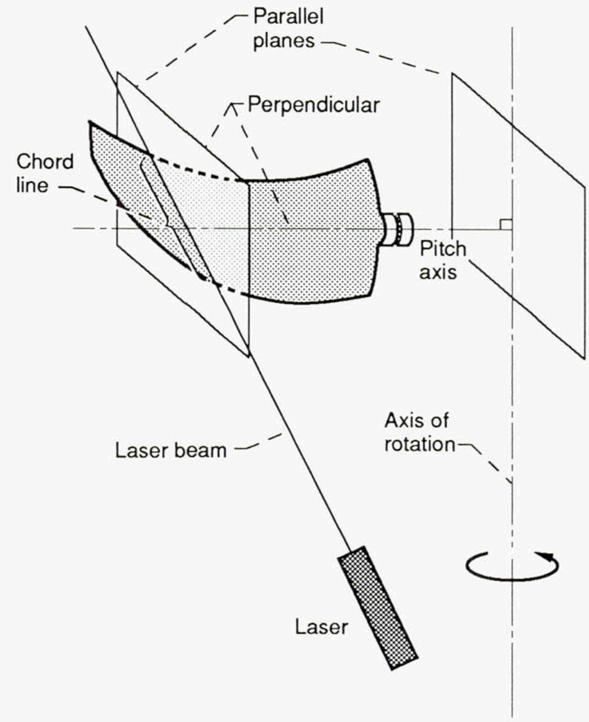


Figure 12.—Laser beam oriented at blade chord setting angle.

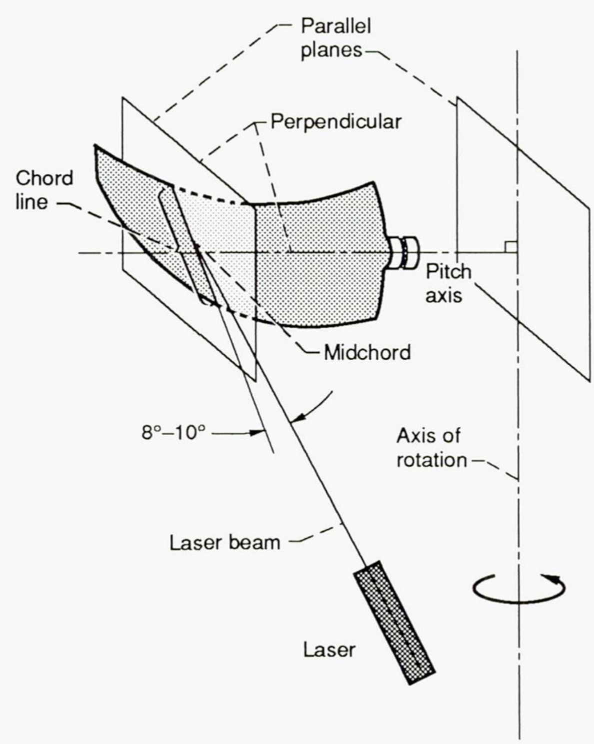


Figure 13.—Final orientation of laser beam with respect to blade chord.

the corresponding midchord point of each marked chord line, as shown in figure 13.

The photodetectors are then placed on the DSF lid so that the unobstructed laser beams impinge on the center of the photodetectors. The once-per-revolution laser is positioned so that the mirror mounted on the rotating shaft passes through the laser beam path, reflecting the beam back to a photodetector. The rubber wedges are then removed from between the base of the propfan blades and the hub, completing the laser setup.

Summary of Results

A nonintrusive optical system for measuring propeller blade deflections has been used in the NASA Lewis dynamic spin facility. Deflection of a point at three leading- and trailing-edge spanwise locations has been successfully measured with narrow light beams from low-power helium-neon lasers. Although the laser setup procedure is tedious, the optical measurement system proved to be extremely versatile.

Acknowledgment

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16. Abstract

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